Geochemical Processes of Geotechnical Significance –

Will the physical properties of your construction materials change over time?

Heath Orcutt (SRK), Kelly Sexsmith (SRK), Adam Leik (SRK)

Photo of Squamish Chief
Source: https://www.andrewswalks.co.uk/the-chief.html

Photo of an ultramafic outcrop
Source: Kelly Sexsmith

Photo of a leach dump at a copper mine
Source: Kelly Sexsmith

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Squamish Chief - granitic rock, strong component
Ultramafic outcrop – may transform to clay
Leach dump at a copper mine, washed with H_2SO_4
Might see breakdown of rock with acid leach
3 different types of material Don't necessarily occur from ARD – they could, but that's not the only mechanism for change

Problem Statement

"The Mine Environment Neutral Drainage (MEND) and International Network for Acid Prevention (INAP) industry organizations are looking to **better understand potential geochemical risks to TSF dam stability** and provide **pragmatic guidance** to mine owners and their consulting teams."

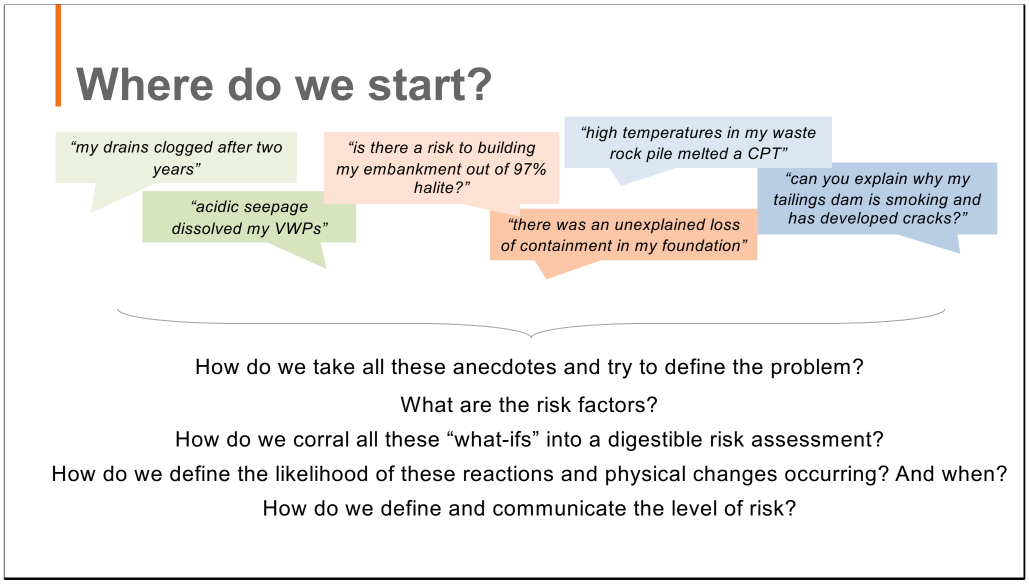
"There does not appear to be extensive published case studies where the problem has materialized. **Prior to communicating the risk** of this problem to the broader industry, MEND and INAP want to **evaluate the plausibility** of geochemical reactions leading to a negative impact on TSF dam stability."

Project Phases

- **Phase 1:** Develop the foundation for an industry focused report which effectively **defines and communicates** the **observed and/or documented geochemical processes** (and resulting physical changes) that could affect a TSFs intended performance over the required service life of a structure.

- **Phase 2:** **Assess the plausibility and credibility** of these risks through the development of a **screening-level risk assessment tool** that identifies the key characteristics and/or combinations of factors that make tailings facilities **more or less prone** to stability risks due to geochemical processes.

Say our intent is not to walk through Phase II – hazard assessment tool
We started with the proof of concept – detailed in the report



Work started out with a literature review

Defining the Main Processes

$2FeS_2 + 7/2O_2\ H_2O \rightarrow Fe^{2+} + 2SO_4 + 2H$

$FeSO_4 + 2H_2O \rightarrow Fe(OH)_2 + H_2SO_4$

$CaMg(CO_3)_2 + 2CO_2 + 2H_2O \rightarrow Ca(HCO_3)_2 + Mg(HCO_3)_2$

$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3$

$2Mg_2SiO_4 + 3H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$

$3Fe^{3+} + 2SO_4^{2-} + K^+ + 6H_2O \rightarrow KFe_3(SO_4)_2(OH)_6 + 6H^+$

$CaSO_4 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O$

Defining the Main Processes

Does the rock or mineral breakdown?

Is a secondary solid formed?

Or something else?

Defining the Main Processes

Does the rock or mineral breakdown?

Defined as the **breakdown of rocks** and minerals by chemical processes such as dissolution, hydrolysis, carbonation, oxidation/reduction, cation exchange, or hydration.

Defining the Main Processes

Does the rock or mineral breakdown?

Is a secondary solid formed?

Precipitation of secondary solids (crystalline and amorphous phases) occurs when solutes released from other geochemical processes reach their solubility limits and the reaction kinetics are favorable for solute precipitation.

Defining the Main Processes

Does the rock or mineral breakdown?

Is a secondary solid formed?

Or something else?

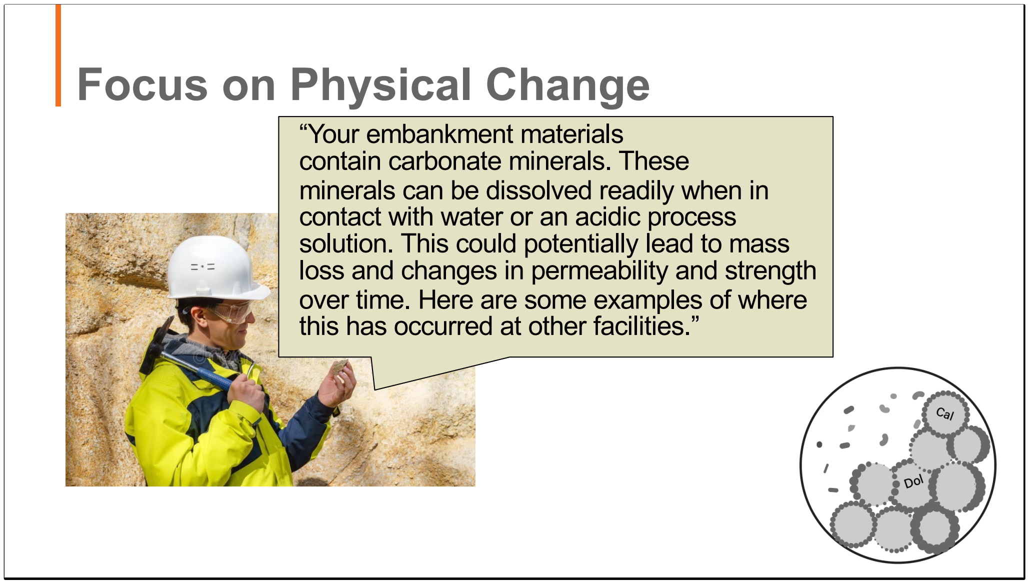
Other water/rock interactions which may have geotechnical implications (e.g., effects of water chemistry on the surface properties of minerals, effects of water chemistry on pipes, concrete, and other infrastructure, etc.)

Processes aren't that important
Whats important is how the material changes – or facility as a whole

Focus on Physical Changes

"Your embankment materials contain carbonate minerals which may undergo dissolution over time, especially if in contact with acidic seepage."

This slide is to explain why we discuss things in terms of physical changes rather than geochemical reactions/processes



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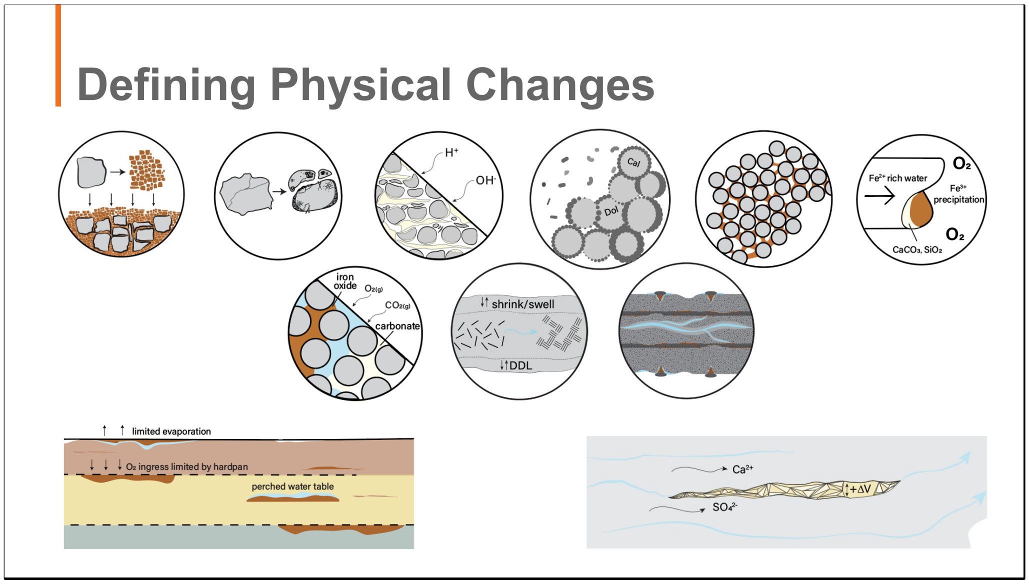
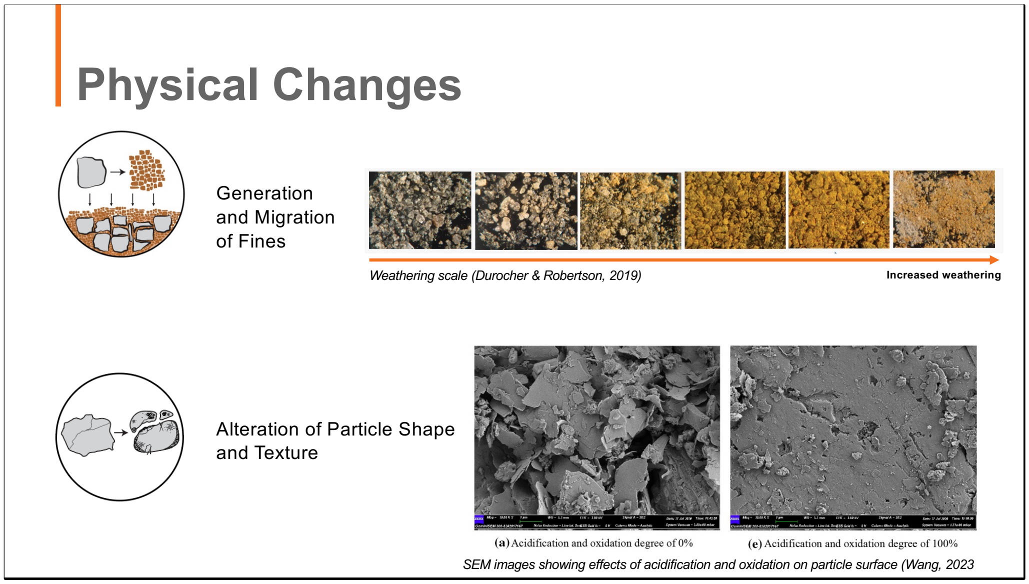


Rather than focus on the geochemical reaction (sulfide oxidation, carbonate dissolution) we tried to look at the outcomes of these different reactions, because often a physical change can be a result of a geochemical reaction

Of course, these are not exhaustive, but based on the literature review I did when I was at CSU and continued at SRK – these are some of the changes that continuously stood out
In the report we dig into more detail on each of these, here is an example..



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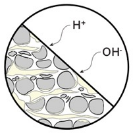
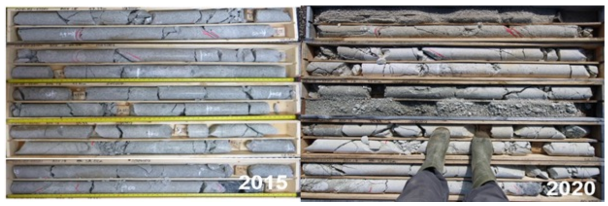
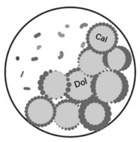


Formation of Clay Minerals



Core boxes after 5 years of weathering (Saunders and LeRiche, 2021)



Mass Loss from Release of Solutes

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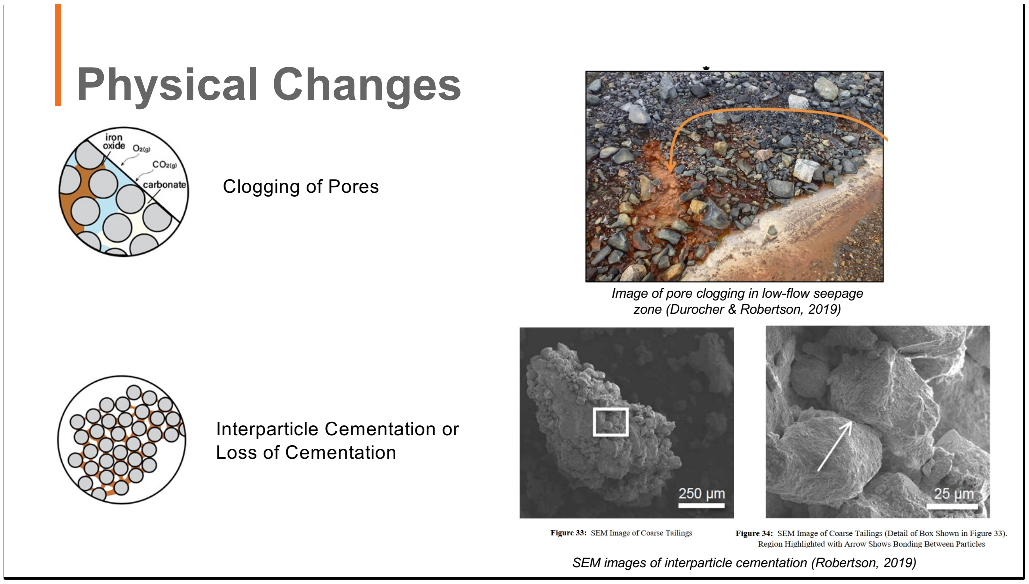

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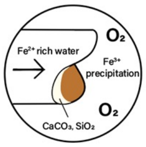
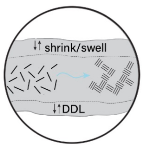


Clogging of Drainage and Scaling of Pipes



Changes in Clay Mineral Properties

Image of pipe clogging (Durocher & Robertson, 2019)

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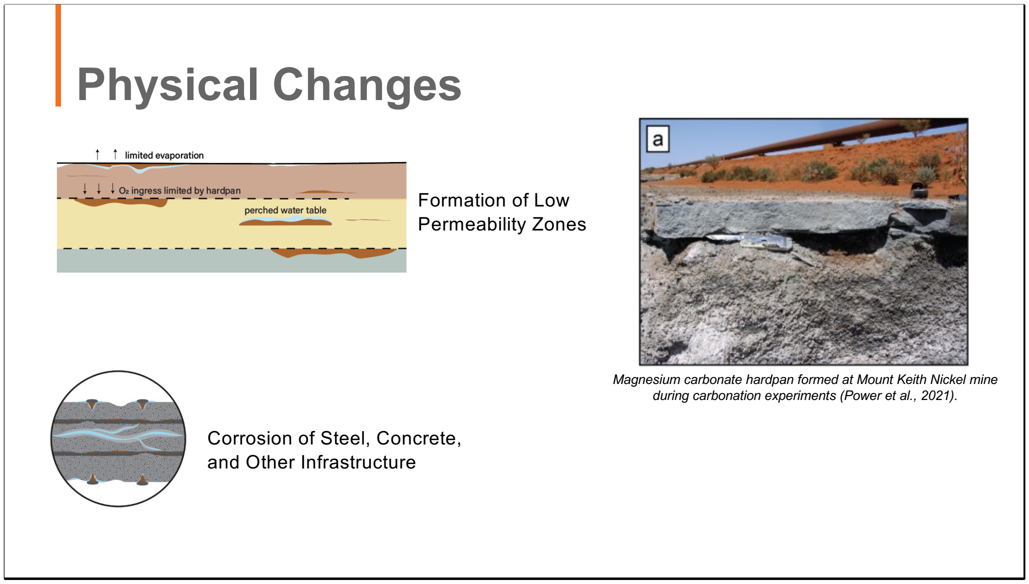

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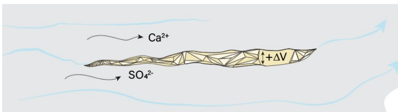
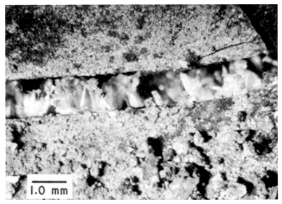


Positive volume change (i.e. sulfide oxidation induced heave)

Observation of gypsum growth in bridge foundation (Alonso and Ramon, 2013)



Shale platelets forced apart by gypsum growth (Penner et al., 1972)

Expansion of drill core from conversion of anhydrite to gypsum (photo by Ed Saunders)

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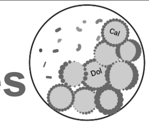
Tabular Literature Review

(4) Mass Loss from Release of Solutes



Physical Change	Description	Potential Geotechnical Significance	Examples	Factors/Conditions that Enhance Plausibility, Significance, or Timescale
(4) Mass loss from release of solutes (W)	Soluble minerals (halides, efflorescent salts, some sulfates, etc.), sparingly soluble minerals (carbonates, gypsum, etc.), and moderately reactive minerals (ultra-mafics, sulfides, etc.) can dissolve upon interaction with acidic and/or neutral pore water, resulting in loss of solids mass. …	➢ Increased void ratio ➢ Increased permeability ➢ Potential for differential settlement ➢ Development of preferential flow paths …	1. Caliche soils comprised of halite, sodium and potassium nitrate, calcite, gypsum and anhydrite are present in the foundation and construction materials of a tailings embankment in Chile. …	Factors that increase the extent of mass loss are low-pH environments, presence of soluble minerals, and wet environments. The rate of carbonate dissolution can be accelerated to relevant time scales under acidic conditions. …

(W) = chemical weathering

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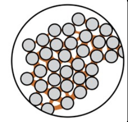
(6) Interparticle Cementation or Loss of Cementation



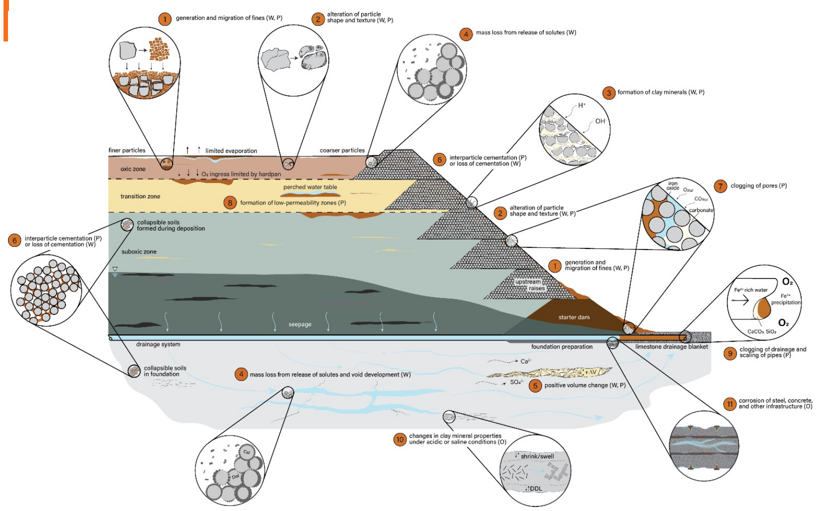
Physical Change	Description	Potential Geotechnical Significance	Examples	Factors/Conditions that Enhance Plausibility, Significance, or Timescale
(6) Interparticle cementation or loss of cementation (W, P)	Precipitates and clay minerals form coatings and/or bridges between individual particles which may contribute to brittle and/or collapsible soils. …	➢ Decreased compressibility and consolidation due to rigid soil skeleton ➢ Increased peak shear strength and low residual strength ➢ Potential for sudden loss of strength …	1. Collapsible soils were detected in the foundation of a proposed TSF. The soils were characterized as relatively low density, high porosity, low moisture content, and partially cemented via salt deposits (Sotelo and Paihua, 2017) …	Collapsible soils are typically found in arid to semiarid regions and form during geological deposition (i.e., aeolian or alluvial fills) under unsaturated conditions. Upon wetting, collapsible soils will experience a large decrease in volume and strength. ….

(W) = chemical weathering, (P) = precipitation of secondary solid phases

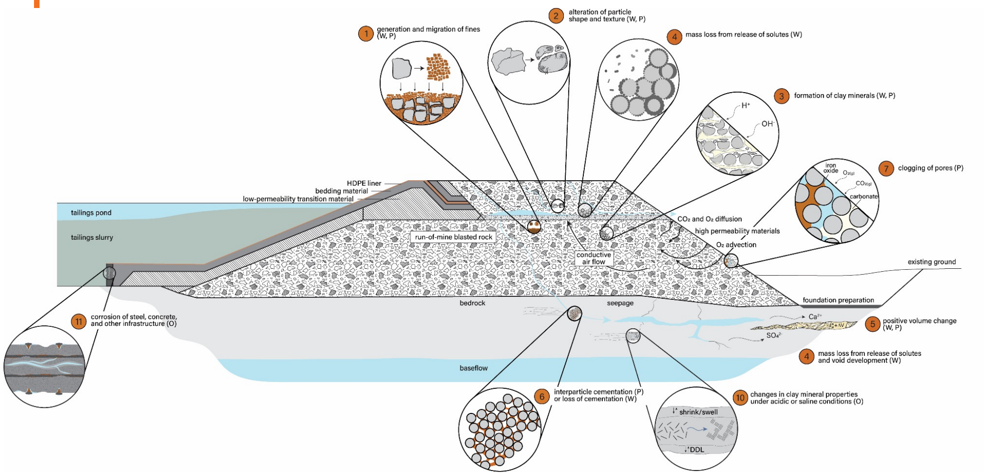
Geochemical Conceptual Models

Where (within a facility) and under what conditions *might* these physical changes occur?

Geochemical Conceptual Models



Geochemical Conceptual Models



Main Takeaways from Phase I

Factors/Conditions that Enhance Plausibility, Significance, or Timescale and

What can we start doing today?

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Main Takeaways

- Geochemical processes may result in physical changes to construction materials and in drainage features **that may not have been present or anticipated during the design** of a tailings storage facility.

- The rate and extent of physical changes varies according to:
  - the susceptibility of the material
  - physical and chemical conditions to which they are exposed to
  - time

Mineral Susceptibility

- Materials that are highly susceptible to change include:
  - Soluble salts
  - High presence of sulfides and carbonates
  - Ultramafic minerals
  - Hydrothermally altered materials or clay minerals
- Many other materials are susceptible to varying degrees of weathering upon breakage and exposure to air and water
- A robust understanding of the geological and mineralogical characteristics of all materials within the facility is critical for understanding how they may change over time

Physical and Chemical Conditions

- The following may increase the rates of geochemical processes:
  - Strongly acidic or alkaline conditions
  - Warmer temperatures
  - Higher rates of water ingress

Time

- Many of the physical changes that occur as a result of weathering reactions evolve over extended periods, from decades to centuries.
  - This long-term perspective is critical for understanding how such changes may influence post-closure performance, even if they present limited risk during active operations.

Measuring and Predicting Change

- It may not be possible to measure geochemically induced changes in physical properties using conventional laboratory tests.
  - ➢ This is a creative challenge for integrated geochemistry and engineering teams!
- For more susceptible materials, it may be possible to couple accelerated kinetic tests – run for sufficient time - with before/after physical tests (strength, permeability, etc.).
- Alternative approaches include:
  - Data from weathered materials at geologically analogous sites
  - Observations and sampling of material exposed in road cuts, pit walls, older drill core, and weathered bedrock
  - Mineral weathering indices

Material Selection

- Where possible, materials that are susceptible to change should be avoided for use in construction, or the material should be blended (sufficiently as to avoid localized weak zones) such that the overall strength of the material meets the design criteria.
- If this is not possible, a range of strength parameters for the weathered material should be used in the facility design.

Design Modifications

- Where possible, materials that are susceptible to generation of solutes and subsequent precipitation of those solutes should be avoided, or controls should be put in place to limit these processes. Controls include:
  - Air traps
  - Oversized drainage systems
  - Designed to promote precipitation reactions further downstream
- If this is not possible, facilities should be designed to avoid reliance on open drains over the longer term.

Final Takeaways

- Facility designs should be **robust** enough to account for potential changes in physical properties and drainage conditions.

- Monitoring plans should include:
  - Regular inspection and periodic sampling of materials to ensure that the physical integrity anticipated at the design state is sustained over time.
  - Regular inspection of drainage features to ensure that precipitates are not altering the hydraulic conditions in unexpected ways.

LINK TO REPORT

Sources

- Alonso, E.E. and Ramon, A., 2013. Heave of a railway bridge induced by gypsum crystal growth: field observations. Géotechnique, 63(9), pp. 707–719.
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